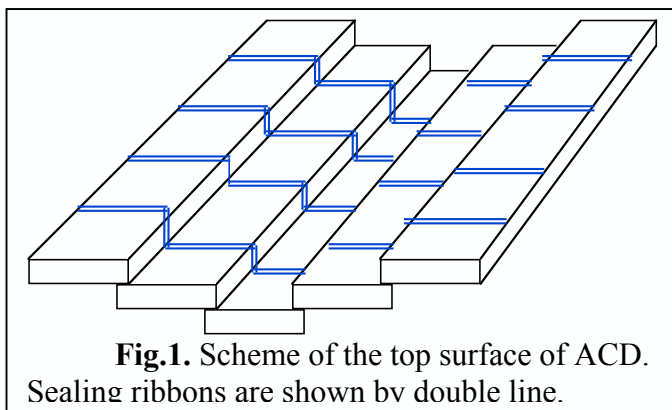
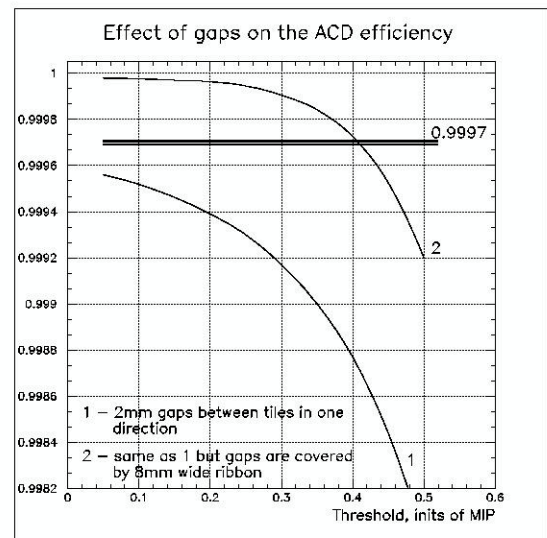


## Sealing of the gaps between ACD tiles – design, simulations and tests

Introduction into the problem. Design of ACD assumes the presence of 2-3mm gaps between the tiles for the wrapping and tile thermal expansion. The effect of these gaps on the ACD efficiency of charged particle detection was studied and results are given in internal notes “ACD Transparency” (A.Moiseev, 05/03/01). It was found that 2mm gaps even in one direction (tiles are overlap in the other) immediately pushes the efficiency of



**Fig.1.** Scheme of the top surface of ACD. Sealing ribbons are shown by double line.

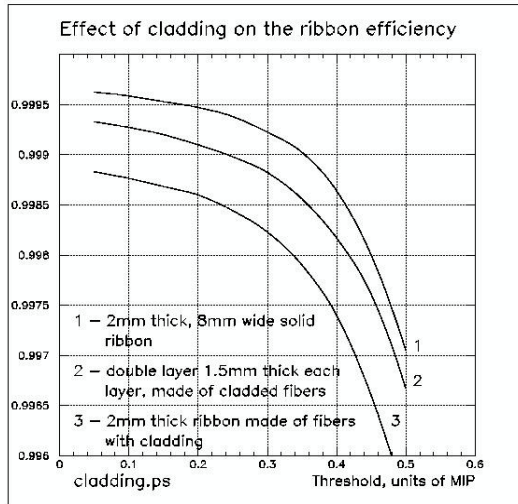


**Fig.2.** Simulated ACD efficiency

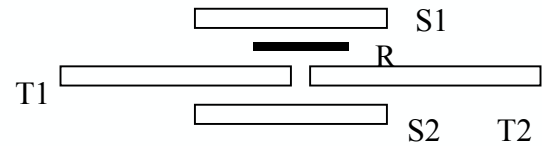
ACD below the required level of 0.9997. One viable way, which was accepted for ACD, is to cover these gaps by pre-bent plastic scintillating ribbon (Fig.1). The simulated efficiency of ACD is shown in Fig.2. It is seen that the required efficiency of 0.9997 for the design with 2mm gaps cannot be achieved at any threshold (line 1). Sealing the gaps by the plastic scintillating ribbon, 2mm thick and 8mm wide, dramatically improves the situation. The mean light yield for the ribbon was assumed to be 5.5 p.e., and the threshold was set at ~0.3 MIP (2 p.e.). These results confirm the design solution to use ribbons to seal the gaps.

Ribbon production and the effect of cladding. We found that needed ribbon cannot be made of the needed length (approximately 3 meters). One more complicating factor is that the ribbon should have cladding for better light propagation. That's why the ribbon was initially assumed to be made of bonded together square scintillating fibers using the extensive experience of the group at Washington University at Saint Louis (W.R.Binns et al.) The design of the ribbon made of square cladded scintillating fibers was simulated. It

was found that the thickness of the cladding (4% of the fiber thickness) creates the dead area sufficient to reduce the efficiency below the desirable level (Fig.3). The simulations were performed for the setup which later was tested with cosmic muons (Fig.4). The 2 mm gap between tested tiles (each is viewed by 2 PMTs) was covered by the ribbon.

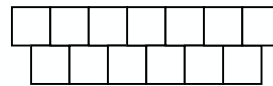


**Fig.3.** Simulations of the effect of cladding for the test setup



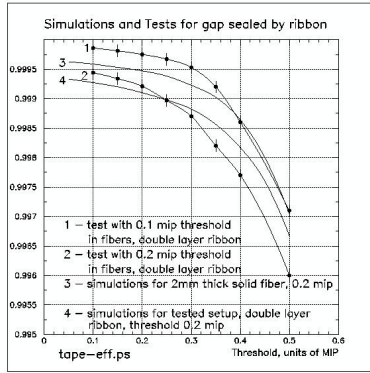
**Fig.4.** Cross-section of the setup. T1 and T2 – tested tiles, R – sealing ribbon, S1 and S2 – triggering scintillators.

corresponds to the 2mm thick, 8mm wide solid ribbon, assuming 5.5 p.e. in average from the MIP and with the threshold at 1.5 p.e. (0.27 of MIP). Events were selected by triggering scintillators S1 and S2, 5cm by 5cm of the area each. Use of these triggering scintillators changes the ratio between the area where the efficiency is being measured, and the area of the gap, that's why the obtained efficiency cannot be directly compared with that given in Fig.2 for the whole ACD. We should use line 1 (for the solid ribbon) as a reference, because it provides proper ACD leakageproof (Fig.2) and compare all other variants with it for the test setup. Line 3 corresponds to the case when we take into account that 2mm thick ribbon is made of separate, 2mm square fibers, each having 4% thick cladding. It is seen that the efficiency drops dramatically. The possibility to resolve this problem is to make the ribbon of 2 layers of fibers, with layers overlapping (Fig.5). Some space between the fibers was also added to account for the glue (obtained experimentally). The simulation results for this ribbon design are shown by line 2 in Fig.4, where the ribbon is made of 1.5mm square scintillating fibers, 6 in one layer, and 7 in the other.



**Fig.5** Structure of double-layer ribbon

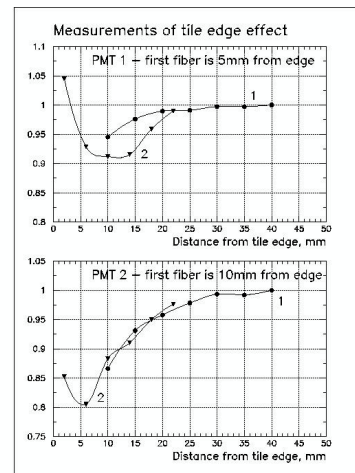
**Test Results.** Fig. 6 shows the test results plotted along with simulations. The tests were performed for the double-layer ribbon described above (Fig.5), and test setup shown in Fig.4. Line 3 (solid ribbon) corresponds to the reference case with which the required ACD performance can be achieved (Fig.2).



**Fig.6.** Test results, compared with simulations, for the proposed ribbon design

The test results are shown by lines 1 and 2 with the thresholds in the ribbon respectively 0.1 MIP and 0.2 MIP. Line 4 shows the simulations for the tested ribbon design, and threshold of 0.2 MIP (to be compared with experimental line 2 – acceptable agreement). The difference between line 2 (test) and 4 (simulations) can be explained by probably higher light output from the fibers (that's why the tested efficiency is higher at lower thresholds) and by some light yield decrease close to the tile edge (edge effect) which causes the faster efficiency drop at higher thresholds.

**Edge effect study.** Expected non-uniformity of the light collection near the tile edges has been studied. The first approach was realized by John Krizmanic, who used radioactive source  $\text{Ru}^{106}$  to activate the scintillation in the tile, and measured the light yield (PHA peak position) moving the collimated source across the tile. The results of the measured relative light yield (scaled to the light yield far from the edge) is given in Fig.7, lines 1 (solid circles data points). Since the tested tile (same tile as used in the efficiency test described above) had 2 PMTs viewing 2 WSF bundles, the measurements were done for both PMTs. The difference between them is that one bundle (PMT1) had a first wave-shifting fiber embedded in the tile closer to the tile edge (5mm), and the second bundle had the first fiber spaced by 5mm from the first one (PMT2). The same measurements were performed by using cosmic muons, and



**Fig.7.** Measurements of edge effect. Lines 1 (solid circles) correspond to the use of  $\text{Ru}^{106}$  (J.Krizmanic), and lines 2 (triangles) are for the test with cosmic muons (A.M.)

determining the position of muon intersection with the tile by the scintillating hodoscope made of 1mm square fibers (A.M.). The results are represented in the same Fig.7 by lines 2 (triangle data points). Finer spatial resolution allowed to get the first measured point closer to the edge, where the light yield increase was observed. This can be due to short-attenuated UV photons, which effectively reflect from the tile edge and increase the light collection. That's why this effect is higher for the PMT1 where the first WSF fiber is closer to the edge. The light yield drop at the distance 5-20mm from the edge, observed in both measurements, can be explained by more limited space for internal light reflection. Anyway, the efficiency measurements for the sealing ribbon (Fig.6) included this area of light yield decrease because 5cm by 5cm triggering scintillators were used. The magnitude of this effect (20% percent of the light decrease at worst) and available light budget (more than 30 p.e. in average for the *MIP*) say that probably this effect is not very serious for the ACD performance. Anyway, in flight ACD tiles the closest to the edge wave-shifting fibers will be placed closer (at least 2 mm), and possibly 2 fibers in one groove (from PMT1 and PMT2) to reduce this effect.

Conclusion. Obtained results demonstrate that the ribbon made of square scintillating fibers, with 2 overlapping layers, will provide us required level of ACD hermeticity. This statement comes from the comparison of experimental line 1 and simulated line 3 (Fig.6), with which required ACD efficiency can be achieved (line2, Fig.2). This design has some margins because the fibers we tested (lines 1 and 2 in Fig.6) are not of the best quality (Paul Hink, private communication) and the light yield from them could be ~30% higher. The proposed design for the ribbon is to make them from 1.5mm cladded scintillating fibers, 17 fibers in total (8 in one layer, and 9 in the other), to fit photocathode of Hamamatsu R-44443 PMT which will be used in GLAST ACD. The use of inner 8.5mm photocathode diameter of the available 10mm diameter is assumed to secure the uniform photocathode sensitivity to all fibers. The best way of fiber bonding inside the ribbon will be determined later. The resulting ribbon sealing width will be slightly over 12mm.